

Deformable Aerodynamic Profile

The present invention relates a deformable aerodynamic profile according to the preamble of Claim 1.

Various arrangements and methods are known for adjusting and optimizing the buoyancy and flow resistance of a body with flow around it, e.g., in the form of an aerodynamic profile, to adapt to various ambient conditions. Such aerodynamic profiles may include helicopter rotor blades, aircraft wings or turbine blades, to name but a few examples.

A number of approaches are known from the field of aeronautical engineering, where deformation of a profile curvature of such aerodynamic profiles is achieved mechanically by using different adjustment devices. However, gaps and hollow spaces then usually occur in the shell of the profile, which is a disadvantage for many applications.

To counteract this problem, DE 196 43 222 C2 describes an arrangement in which the properties of flow around a body are modified by continuous deformation of an aerodynamic profile having an elastically deformable shell using an adjustment device integrated into the profile.

Furthermore, DE 197 09 917 C1 describes a device for controlled deformation of a shell structure, having a number of bulging ribs, which are joined together by actuators to achieve a change in the curvature of an elastic component connected to the bulging ribs.

In addition, composite structures for producing and detecting deformation are known from the state of the art; these structures have a plurality of piezoelectric fibers running parallel (e.g., United States Patent 5,869,189 and United States Patent 6,048,622). However, it is a disadvantage here that these fibers are not only very expensive but are also relatively inefficient because of their great weight. Furthermore, suitable contacting of the piezoelectric fibers is necessary, and another factor to be taken into account is achieving the most homogeneous possible field distribution, which is necessary for producing the piezoelectric effect. The electrodes required for this may be provided, for example, by separate layers, i.e., electrode layers which can be integrated into the composite structure only with a corresponding extra technical expense. When using this known composite structure to induce deformation, it is also a disadvantage

that as a rule a high voltage is necessary for triggering the piezoelectric fibers. This means not only that a high energy demand is necessary, which makes the arrangement inefficient, but also that a complex electronic control system is necessary. In addition, suitable safety provisions must be taken.

It is thus the object of the present invention to create a deformable aerodynamic profile whose profile curvature can be varied in a technically simple and effective manner.

This object is achieved by an aerodynamic profile which has a front profile area and a rear profile area situated in the downflow and is bordered by a shell on the pressure side and on the suction side, converging at a rear edge of the profile; this profile is characterized according to this invention in that it is equipped with d33 piezo actuators in at least some spots for its deformation such that their change in length occurs essentially in the direction of the planes of the shells when acting upon by electricity.

Due to the use and appropriate alignment of piezoelectric actuators with a so-called longitudinal effect (d33 effect), where the change in length of the piezoelectric material takes place in the direction of the electric field which is known to be greater than the usual piezo effect (d31 effect) in which the change in length is perpendicular to the electric field, more effective introduction of forces into the aerodynamic profile is possible.

It is especially expedient to arrange the d33 piezo actuators on the pressure side and/or suction side of the shell. The shells are usually made of conventional construction materials and the d33 piezo actuators are attached, e.g., by adhesive bonding. However, mechanical fastening means (e.g., clamping devices or screwing devices) may also be used for fastening. In addition, the shell provided with the piezo actuators may also be provided with a protective layer to protect the piezo actuators from impact, pressure, pulling or other external influences (including environmental factors).

According to another embodiment, the d33 piezo actuators are integrated into the shell on the pressure side and/or suction side. This configuration is preferred in so-called composite structures which may be metallic but may also be so-called MMCs (metal matrix composites). Likewise, the d33 piezo actuators may be integrated into composite fiber structures. One advantage here is that the piezo actuators are automatically protected.

Similarly, the inventive principle may also be applied to other floating bodies, which are attached with an articulated joint to the aerodynamic profile, for example, e.g., control flaps. In this case the control flap is provided with d33 piezo actuators and the d33 piezo actuators are in turn aligned so that their change in length takes place essentially in the plane of the flap when exposed to an electric current in a similar manner. A design in which the flap provided with d33 piezo actuators is connected to the rear profile edge of the aerodynamic profile with an articulated connection is particularly advantageous.

It is especially advantageous for the d33 piezo actuators to be used in the form of stacks of piezoelectric elements (so-called piezo stacks) which are known to have a laminar structure with alternating electrode layers and layers of piezoelectric material (therefore are also referred to as "laminar" piezo actuators). This has the advantage that the electrodes are integrated into the piezo actuator, which greatly facilitates contacting of the piezo actuator and at the same time ensures a homogeneous field distribution within the piezo actuator. It is especially expedient that the electric field for inducing the d33 effect is supplied via the electrodes integrated into the laminar piezo actuator. The inventive arrangement can therefore be implemented especially effectively and in a technically simple manner.

Furthermore, it is expedient for the laminar d33 piezo actuators to have a low thickness of approx. 0.5 to 2.5 mm so that they have hardly any influence at all on the flow conditions. It is advantageous that such thin-layered d33 piezo actuators can easily be introduced or integrated into the shells of aerodynamic profiles and have a low weight.

Furthermore it is expedient that the side dimensions of the d33 piezo actuators are between 5 and 60 mm. This permits easy adaptation to given geometries (e.g., corners, edges, rounded shapes, etc.).

The inventive principle is used mainly in helicopter rotor blades, aircraft wings, turbine blades or the like.

This invention is explained in greater detail below on the basis of the accompanying figures, in which:

FIG 1 shows a schematic three-dimensional view of an aerodynamic profile with d33 piezo actuators,

FIG 2 shows a schematic diagram of a stacked piezoelectric element to illustrate

- a) the d33 effect and
- b) the d31 effect;

FIG 3 shows schematic views to illustrate a torsional convexity on the basis of

- a) a partial cross-sectional view of a shell; and
- b) a top view of the detail shown in FIG 3a;

FIG 4 shows a sectional view of another embodiment of an inventive aerodynamic profile; and

FIG 5 shows a schematic three-dimensional view of an aerodynamic profile with the control flap connected by an articulated joint.

FIG 1 shows in general form an aerodynamic profile 1 in a schematic three-dimensional diagram. The profile 1 has a front profile area 2 and a rear profile area 3 situated on the downflow side. To illustrate this, FIG 1 shows the direction of flow with the arrow S_{flow} . The profile 1 is bordered in a known way by a shell 4 on the pressure side and a shell 5 on the suction side, converging in a rear profile edge 6 in the rear profile area 3. The rear profile edge 6 runs in the width direction S_{width} . Such an aerodynamic profile 1 may be, for example, a helicopter rotor blade or an aircraft wing, both of which are well known in the state of the art, so that no further description of individual details is needed here.

The aerodynamic profile 1 is also provided with piezo actuators 7, which are arranged on the shell 5 on the suction side in the embodiment according to FIG 1. The actuators may of course also be provided either additionally or exclusively on the shell 4 on the pressure side, depending on the demands of the application. The piezo actuators 7 are attached to the shell(s) by gluing or by using other fastening means (e.g., clapping devices, screwing devices, etc.).

These piezo actuators 7 have the so-called d33 effect (longitudinal effect), which is explained in greater detail in conjunction with FIG 2.

FIGS 2a and 2b show in schematic diagrams a stacked piezoelectric element 8 (also known as piezo stack) which is constructed of alternating layers of electrically conducting material and piezoelectric material, as is already known. The layers of electrically conducting material are electrodes 8a. In the case shown in FIG 2a, the electric field E runs in the stack direction and/or the longitudinal direction of the piezoelectric element 8, with the electric field E expediently being provided by the electrodes 8a. Because of the electric field E , the piezoelectric material expands in the direction of the electric field E . This change in length is labeled as ΔL in FIG 2a and is known to be greater than the change in length Δl in the d_{31} effect, in which the change in length Δl occurs across the electric field E (see FIG 2b).

The piezo stack 8 shown in FIG 2a has been cut in the longitudinal direction for use as d_{33} piezo actuators 7 for the aerodynamic profile diagrammed schematically in FIG 1; the laminar structure with alternating layers of piezoelectric material and electrically conducting material is retained. The thickness d of the piezo actuators 7 cut in this way typically amounts to 0.5 to 2.5 mm and the side dimensions a and b are typically between 5 and 60 mm.

The arrangement of the cut laminar d_{33} piezo actuators 7 on the aerodynamic profile 1 is based on the application, so the profile curvature can be varied in the desired direction. This is explained again in greater detail below with reference to FIG 1. FIG 1 shows as an example three d_{33} piezo actuators 7 arranged in the front profile area 2. The d_{33} piezo actuators 7 are aligned so that the change in length ΔL when the d_{33} piezo actuators 7 are acted upon by electricity within the shell 5 takes place in the direction of flow S_{flow} , which is indicated with the double arrow A in FIG 1. In addition, the d_{33} piezo actuators 7 may also be arranged in such a way that their change in length takes place in the plane of the shell 5 in the width direction, which is represented by the actuator 7, arranged near the rear edge 6. The direction of the change in length of this actuator is labeled with the double arrow B here. The piezo actuators 7 may of course also be arranged in such a way that the change in length within and/or parallel to the planes of the shell points in a direction between the directions A and B (not shown in FIG 1). Minor deviations, e.g., due to the fact that it is not fastened completely flatly on the shells (i.e., the piezo actuators are at a slight inclination with respect to the planes of the

shells) are harmless and are within the range of tolerance. It is essential here that the d33 piezo actuators are arranged in such a way that their change in length when acted upon by electricity runs essentially in the direction of the planes of the shells 4 and/or 5. Corresponding changes in length in the plane of the shells 4, 5 and thus curvature can be achieved in this way.

For the case when torsion of the aerodynamic profile 1 is desired, the d33 piezo actuators 7 are arranged in a similar manner on both sides of the respective shell 4 and/or 5, which is explained in greater detail below with reference to FIGS 3a and 3b. FIG 3a shows as an example a partial cross-sectional view of the shell 4 on the pressure side with d33 piezo actuators 7 attached to its top and bottom sides 4a, 4b. As described previously, the d33 piezo actuators 7 are arranged in such a way that their length changes essentially in the direction of the plane of the shell when acted upon by electricity, they undergo a change in length essentially in the direction of the plane of the shell. The piezo actuators 7 on the top and bottom sides 4a, 4b, however, have a different orientation with respect to one another, as depicted in FIG 3b, which is a top view of the detail shown in FIG 3a. The d33 piezo actuators 7 arranged on the top side 4a points in a direction A' within the plane of the shell 4, and the piezo actuators 7 (shown with dotted lines) arranged on the bottom side 4b points in a direction B'. Due to this "crossed" arrangement, torsion is induced in the respective shell on actuation of the piezo actuators 7.

According to another embodiment, which is not shown here, the thin d33 piezo actuators 7 can be integrated into the shells 4, 5 on the pressure side and/or on the suction side. Such a design is beneficial, for example, when the shells are made of composite materials. Due to the integration of the piezo actuators into the composite structure, the actuators 7 are protected, while on the other hand the most symmetrical possible curvature is achieved. The latter is advantageous in particular when the shells have a relatively great thickness in relation to the actuator thickness d. Such an integrated arrangement is typically used with composite structures (e.g., metallic composite structures, MMCs, fiber composite materials, etc.).

In a special embodiment of this design, which is depicted schematically in FIG 4, the shells are not designed separately of a composite material but instead the entire profile is designed as a composite material. In this case

the aerodynamic profile 1 is not hollow but instead has a compact design and the piezo actuators 7 are arranged inside the profile 1, a piezo actuator 7 being depicted only schematically in FIG 4.

Furthermore it should be pointed out that the active principle of this invention can also be applied similarly for other profiles that are exposed to oncoming flow and are mounted on the aerodynamic profile 1, for example. This is indicated schematically in FIG 5, showing an aerodynamic profile 1 which has another oncoming flow profile pivotably hinge-connected to its rear profile edge 6. For deflection and/or curvature of the flap 9, the d33 piezo actuators 7 are mounted on the flap 9 in this exemplary embodiment, whereby the change in length of the d33 piezo actuators when they are acted upon by electricity takes place in the direction of the plane of the flap 9, like the arrangement described in conjunction with FIG 1.

In each of the embodiments described above, the piezo actuators 7 may be sheathed with electrically insulating material (e.g., ceramic, polymer, etc.) completely or only at the interface with the structure (e.g., shell 4, 5 on the pressure side or on the suction side) or [coated] to ensure insulation of the structure. This is relevant in particular when the structure to which the piezo actuator is applied is electrically conducting. Similarly, such a sheathing may also be used for protective purposes.

The stacked d33 piezo actuators used here may be supplied with electricity via the electrodes 8a in a simple manner, as described above. The operating voltage is typically in the range of 50-500 V and contacting of the electrodes 8a can be accomplished through soldered connections or bus connections that are technically easy to implement.

The inventive principle explained above is used mainly in the curvature of helicopter rotor blades, aircraft wings, turbine blades or similar applications. However, use of the inventive idea is not limited to these specific examples.